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UNITS AND MEASUREMENTS

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1. INTRODUCTION.

1.1 It is almost impossible to discuss "Units and Measurements" at any length without mentioning 'Physics'. Physics is an experimental and observational science dealing with the properties and inter-relations of matter and energy. Its method is to make observations and measurements from which laws and formulae may be deduced. These laws and formulae may then be used to make predictions about the behaviour or objects under certain specified conditions.

1.2 Many of the greatest and most important discoveries of science have only been made as the result of very accurate measurements. Experience shows that in many cases assumptions made as a result of our sensory responses can be quite misleading. As an example, the blade of a spade left out in the sun may appear to our touch to be much hotter than the wooden handle; measurement with a thermometer shows the temperature of both to be substantially the same. Other senses may be similarly mislead so that the scientist or the engineer or the tradesman prefers to substitute measurements with instruments. In this way he obtains much more consistent and reliable information.

1.3 This paper describes systems of units and methods of obtaining accurate information by measurement.

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UNITS AND MEASUREMENTS

2. SYSTEMS OF UNITS.

2.1 THE SI SYSTEM. In 1960 the General Conference of Weights and Measures adopted the following six units and quantities as the basis of a practical system of measurement. A seventh unit "the mole" has been proposed.

Quantity	Unit	Symbol
length	metre	m
mass	kilogramme	Kg
time	second	s
electric current	ampere	A
temperature	degree Kelvin	^{o}K
luminous intensity	candela	cd

TABLE 1. BASIC UNITS OF SI SYSTEM.

Units defined in terms of these basic units are termed International Units (abbreviated to SI units from the French "Systeme Internationale").

A basic or fundamental quantity is one for which the unit size is selected in an arbitrary fashion. For example, the SI unit of length is the metre, which is defined as "the length equal to 1650763.73 wavelengths in vacuum of the orange light emitted by the krypton atom of mass 86". The SI unit of time is the second, which is defined as a certain fraction of the tropical year 1900. While it has been necessary for scientific research to have these precise definitions, for normal usage the length of one metre and the time interval of 1 second remain unchanged from the values that have been in use for some time.

Any other quantities whose units are defined in terms of the basic units are referred to as "derived quantities". Examples of derived quantities are area, volume, speed and momentum.

2.2 OTHER SYSTEMS OF UNITS. Prior to the introduction of the SI system of units, three other systems were in common use. These were the MKS system, the CGS system and the FPS or British system. The units of length, mass and time for each of these systems are shown on Table 2.

System	Length	Mass	Time
MKS	metre	kilogramme	second
CGS	centimetre	gramme	second
FPS	foot	pound	second

TABLE 2. UNITS OF OTHER SYSTEMS.

2.3 COHERENT UNITS. The SI system is a coherent system. By this we mean that the unit of a derived quantity is obtained from the quotient or the product of any two of the basic units. For example, the unit of velocity in the SI system is the metre per second, where the metre is the unit of length and the second is the unit of time. The kilometre per hour is not a standard velocity unit in the SI system.

2.4 METRIC MULTIPLES AND SUB-MULTIPLES. In some instances, the standard unit may be either too big or too small for practical common applications. Multiples and sub-multiples of metric units are formed by using the prefixes shown in Table 3. The prefixes deca and hecto are now very seldom used.

Factor by which Unit is Multiplied	Prefix	Symbol
1 000 000 000 000 = 10^{12}	tera	T
1 000 000 000 = 10^{9}	giga	G
1 000 000 = 10^{6}	mega	M
1 000 = 10^{3}	kilo	k
100 = 10^{2}	hecto	h
10 = 10^{1}	deca	da
0.1 = 10^{-1}	deci	d
0.01 = 10^{-2}	centi	c
0.001 = 10^{-3}	milli	m
.000 001 = 10^{-6}	micro	µ
.000 000 001 = 10^{-9}	nano	n
.000 000 000 001 = 10^{-12}	pica	p

TABLE 3. METRIC MULTIPLES AND SUB-MULTIPLES.

2.5 UNITS OF VOLUME. In SI units, the unit of volume is the cubic metre. For the measurement of fluid volumes, two other units in common use are the litre and the gallon. Glassware for measuring fluids is commonly graduated in millilitres; one millilitre is approximately equal to one cubic centimetre.

2.6 COMPARISON OF UNITS OF LENGTH. Although Australia intends to convert to metric measurements in the mid 1970's, for some time there will exist in practice both metric and English units, and a tradesman will need to be conversant with both systems. Table 4 shows the common units of length used in metric and British systems.

12 inches = 1 foot	10 millimetres (mm) = 1 centimetre (cm)
3 feet = 1 yard	10 centimetres = 1 decimetre (dm)
22 yards = 1 chain	10 decimetres = 1 metre
80 chains = 1 mile	1000 metres = 1 kilometre
1760 yards = 1 mile	
5280 feet = 1 mile	
100 links = 1 chain	

Approximate Comparisons
1 metre = 39.37 inches
1 cm = 2/5 inch approx. 1 inch = 2.54 cm.
1 kilometre = approx. 5/8 mile

TABLE 4. COMMON UNITS OF LENGTH-BRITISH AND METRIC.

3. ACCURACY IN MEASUREMENTS.

3.1 In Section 1, we discussed briefly how the senses can be deceived regarding temperature, and mentioned that it would be far better to use a temperature measuring device such as a thermometer.

Similarly, it would be most unwise to rely on an estimation of distance or length. One of the most common measurements made by any tradesman is length; the measuring tool or device used depends on the length to be measured. Some of the more common tools used for measuring length include steel or wooden rules, a flexible 6 foot steel rule and a fabric measuring tape (Fig. 1). Care should be taken with the fabric tape as it is often strengthened with a metallic thread and could therefore be a conductor of electricity.

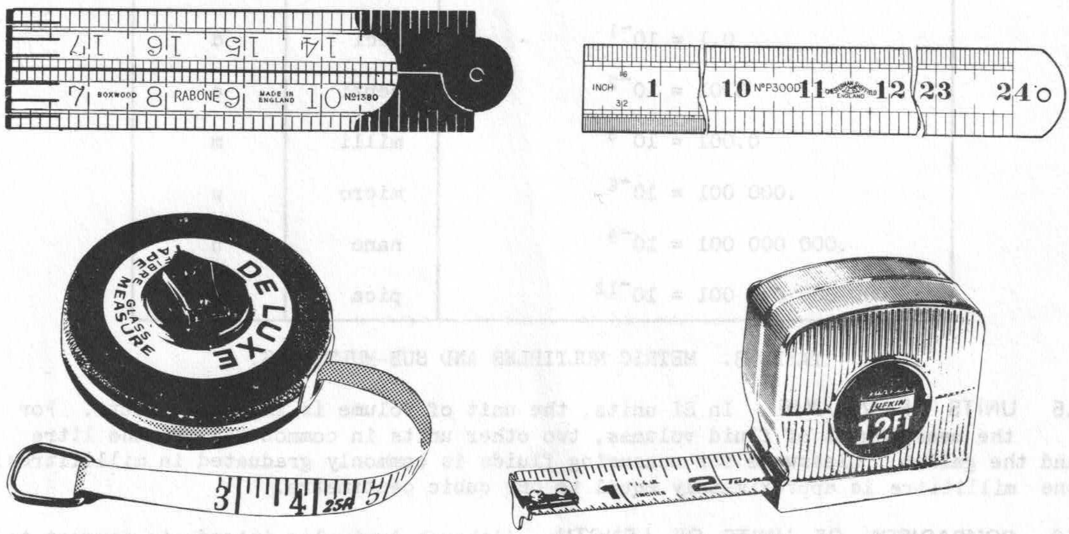


FIG. 1. LENGTH MEASURING TOOLS.

3.2 As every measurement taken with tools as shown in Fig. 1 still requires use of the senses, each measurement is subject to some degree of error of observation, but with care errors can be kept to a minimum. If the following rules are observed, the measurements taken should be reasonably accurate:

- As the end of a rule may be worn, start your measurement from one of the major divisions such as the 1 inch mark. Remember that you must deduct one inch from the final measurement. Fig. 2 shows a measurement being made, starting from the 1 inch division on the rule.

- When measuring flat objects lengthwise, be sure that the rule is parallel with the edge of the work. When measuring width, make sure that the rule is at right angles to the edge (Fig. 2).

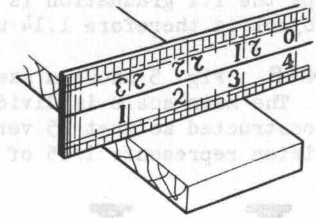


FIG. 2. ACCURATE MEASUREMENTS WITH A RULE.

- Place the rule on its edge as shown in Fig. 2 so that the graduated edge is as close as possible to the surface to be measured. Fig. 3 shows how "parallax error" can occur if the rule is laid flat and the eye is not exactly above the point of measurement.

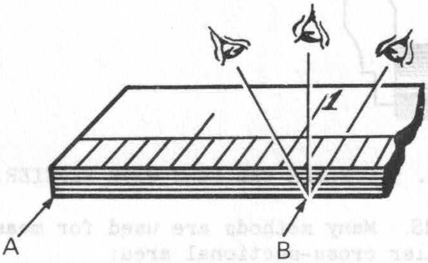


FIG. 3. INCORRECT READINGS RESULTING FROM PARALLAX ERROR.

- It sometimes happens that the point of measurement does not coincide exactly with any calibration on the rule. In such a case it is necessary to estimate fractions of a division.

When an estimate may not be sufficiently accurate, a more accurate result may be obtained by using an instrument which incorporates a vernier, (Fig. 4).

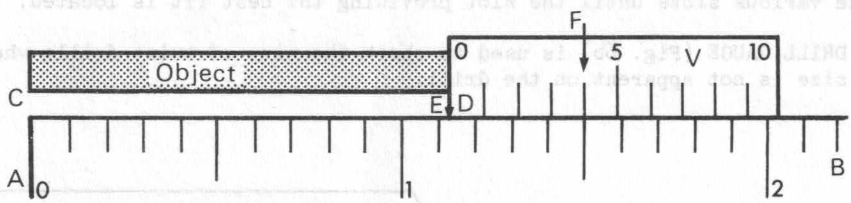


FIG. 4. THE VERNIER PRINCIPLE.

3.3 THE VERNIER PRINCIPLE. The vernier is an auxiliary scale used in conjunction with a main scale to assist in estimating fractions of a main scale division. Let us suppose the AB in Fig. 4 is a main scale divided into tenths of a unit. The object to be measured is obviously between 1.1 and 1.2 units in length; estimation by eye places its length somewhere between 1.13 and 1.15 units.

In this case the vernier scale is constructed so that a length corresponding to 9 of the main divisions is divided into 10 equal parts. Each vernier division is .09 of a unit and is .01 of a unit shorter than a main scale division. To find the amount by which the object overlaps the 1.1 division, the vernier scale 0 is placed at the end of the object, and the vernier division which most nearly coincides with a main scale division is noted.

In Fig. 4, the fourth vernier division is coincident with a main scale division. The amount that the object overlaps the 1.1 graduation is equal to 4 × 0.01 or 0.04 units. The total length of the object is therefore 1.14 units.

3.4 SLIDE CALIPERS WITH VERNIER. Fig. 5 shows a sketch of slide calipers fitted with a vernier scale. The main scale is divided into fortieths (0.025 inch) and the vernier is constructed so that 25 vernier divisions equal 24 main divisions. Each vernier division represents 1/25 of 1/40 or 0.001 inch.

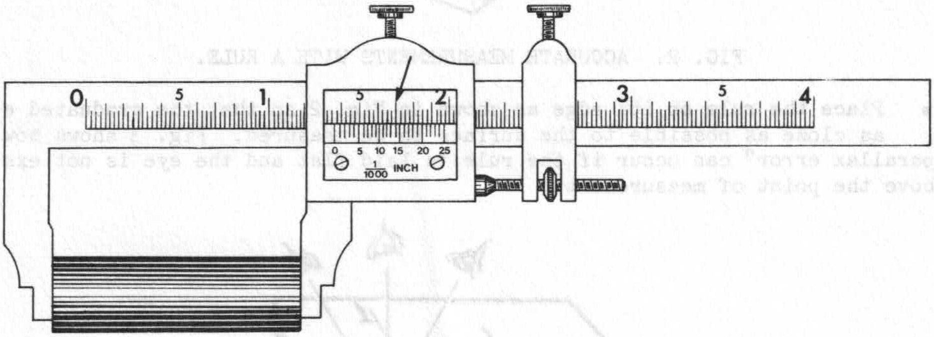


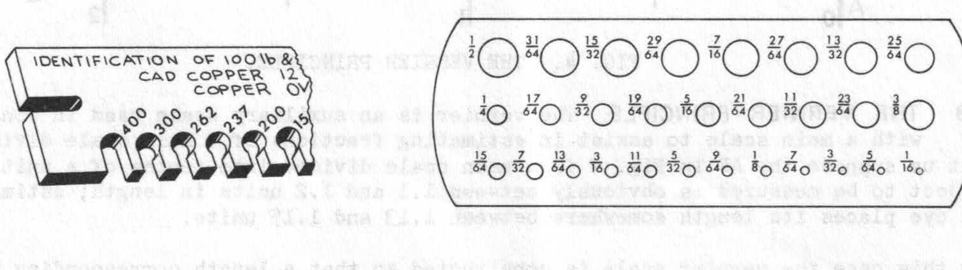
FIG. 5. SLIDE CALIPERS WITH VERNIER.

3.5 MEASURING DIAMETERS. Many methods are used for measuring diameters of objects having a circular cross-sectional area:

- GO, NO-GO gauge is used to determine whether a particular item is within allowable limits. The simplest form consists of a flat piece of steel with machined slots, one slot marked GO and the other marked NO-GO. To pass a test the item must fit in the slot marked GO and not in the slot marked NO-GO.

- WIRE GAUGE. A wire gauge is used to determine the diameter of a particular sample of wire. The gauge (Fig. 6a) consists of a flat piece of steel with a number of slots along its edge. The diameter of a wire is gauged by trying it in the various slots until the slot providing the best fit is located.

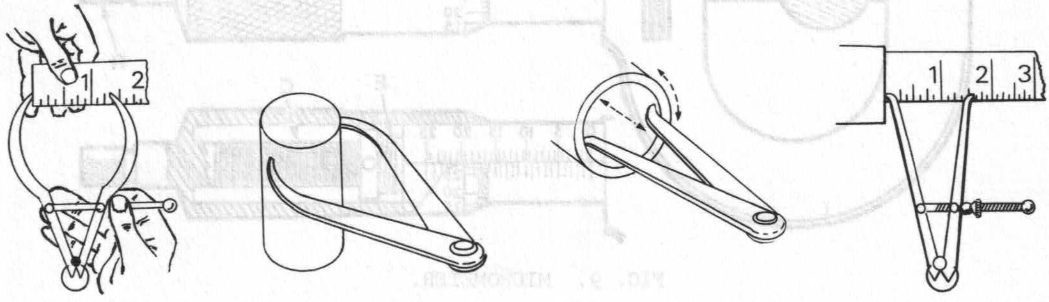
- DRILL GAUGE (Fig. 6b) is used to check the size of twist drills when the size is not apparent on the drill.



(a) Wire Gauge. (b) Drill Gauge.

FIG. 6. WIRE AND DRILL GAUGES.

- CALIPERS. Outside calipers Fig. 7a are used to measure the outside diameter of cylindrical shapes. Inside calipers (Fig. 7b) are used to measure the inside diameter or bore of hollow cylindrical objects such as pipes. As the calipers are not fitted with a scale, the measurement is taken and the calipers are measured on a rule.



(a) Outside Calipers. (b) Inside Calipers.

FIG. 7. TYPICAL CALIPERS.

- RULE AND SQUARE. Fig. 8 shows how a rule and two squares may be used to obtain an accurate measurement of the diameter of a cylinder.

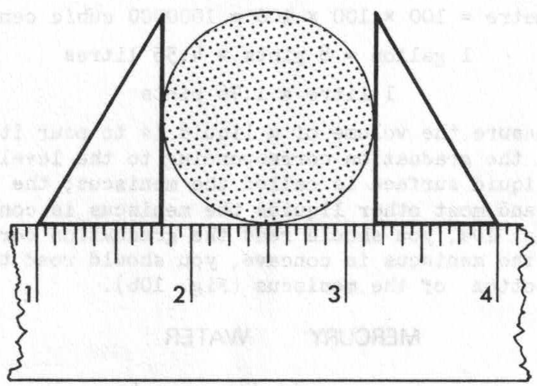


FIG. 8. USING RULE AND SQUARES TO MEASURE DIAMETER.

- MICROMETER. Very accurate measurements may be made by using a micrometer (Fig. 9), which uses the screw principle for estimating fractions of a scale division. When a screw rotates one turn, its end moves through a distance equal to the "pitch" of the thread, which is the distance from apex of one thread to that of the next. In the example shown in Fig. 9, the micrometer has a main screw C with a pitch of 0.5mm rotating through a fixed nut E. For each complete revolution of the screw, the end A moves 0.5mm; the number of revolutions made when measuring the object between A and B is found by noting the position that the end of the sleeve G occupies on the scale S. The bevelled end of the rotating sleeve G has a scale M which divides the circumference into 50 equal parts. Each division on this scale corresponds to a movement of 1/50 of 0.5mm or 0.001cm.

A good quality micrometer is usually fitted with a ratchet R to turn the screw. When the correct pressure is being applied to the object under measurement, the ratchet slips, enabling a positive contact without undue force. Micrometers in general use in engineering workshops have a screw thread of pitch of 1/40 inch (0.025 inch) and a cylindrical scale M divided into 25 equal parts; each division therefore represents 0.001 inch.

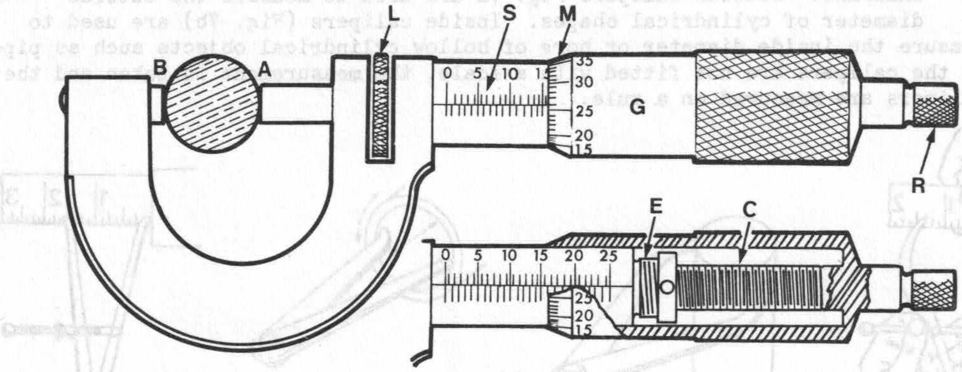


FIG. 9. MICROMETER.

3.6 MEASUREMENT OF VOLUME. The volume of a body is the amount of space it occupies. In SI units the volume unit is the cubic metre, the unit in the British system is the cubic foot. When measuring fluid volumes, two common units are the litre (metric) and the gallon (British).

$$1 \text{ litre} = 1000 \text{ cubic centimetres}$$

$$1 \text{ cubic metre} = 100 \times 100 \times 100 = 1000000 \text{ cubic centimetres}$$

$$1 \text{ gallon} = 8 \text{ pints} = 4.55 \text{ litres}$$

$$1 \text{ litre} = 1.76 \text{ pints}$$

The simplest way to measure the volume of a liquid is to pour it into a graduated cylinder and then read the graduation corresponding to the level of the liquid surface. The curved liquid surface is called the meniscus; the mercury meniscus is convex, but for water and most other liquids the meniscus is concave. When the meniscus is convex, Fig. 10a, you should read the graduation corresponding to the top of the meniscus; when the meniscus in concave, you should read the graduation corresponding to the bottom of the meniscus (Fig. 10b).

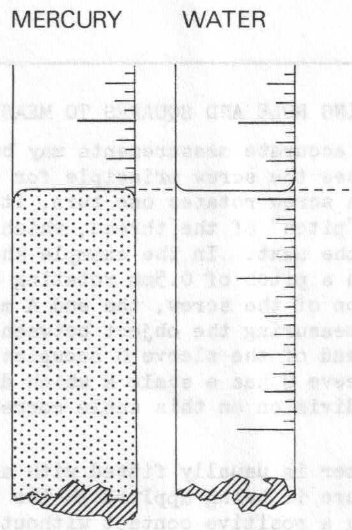


FIG. 10. MEASUREMENT OF LIQUIDS IN A FLASK.

To measure the volume of a solid in the form of a cube, rectangular block, sphere of cylinder, measure its dimensions and then calculate the volumes as follows:-

- Volume of cube = L^3
- Volume of rectangular block = $L \times B \times D$
- Volume of sphere = $4/3\pi R^3$
- Volume of cylinder = $\pi R^2 L$

where

L = length

B = breadth

D = depth

R = radius

π = 3.14 approx.

4. FORCE, WORK, POWER AND ENERGY.

4.1 FORCE AND WORK. In the scientific sense, a force may be regarded as anything which tends to set a stationary body in motion or to change the speed of direction of motion of a moving body. A force can be applied to a large or heavy object without causing motion. If a body is already moving, the effect of a push or pull applied to it will be to make it move faster or slower or to change its direction of motion. In everyday language, work denotes any mental or muscular activity, but in science it is used in a technical sense and is given a strictly limited meaning. "When a force moves so that there is motion along the direction of the force then work is done". No matter how great the force exerted on a body, no work is done unless motion occurs.

4.2 UNITS OF FORCE. Unit force in any system of units is that which, when acting on unit mass, produces unit acceleration.

$$F = ma$$

where m = mass and a = acceleration.

- The SI force unit, the Newton (symbol N) is that force which gives a mass of 1 kilogramme an acceleration of 1 m/s^2 in the direction of the force.
- The CGS unit, the Dyne (symbol dyn) is that force which gives a mass of one gram an acceleration of 1 cm/s^2 in the direction of the force.
- The British technical force unit, the pound force (symbol lb.f) is that force which gives a mass of one slug an acceleration of 1 $foot/s^2$ in the direction of the force.

1 newton = 10^5 dyne

1 pound force = 4.44 newton

Practical applications of force are discussed in the paper "Basic Mechanics".

4.3 UNITS OF WORK. In any system of units, unit work is done when unit force moves its point of application a unit distance in the direction that the force is acting:-

- The SI unit of work, the joule (symbol J) is the work done by a force of one newton moving its point of application a distance of one metre in the direction that the force is acting.

- The CGS unit of work, the erg, is the work done by a force of one dyne moving its point of application a distance of one centimetre in the direction that the force is acting.

(10^5 dyne = 1 newton, 10^2cm = 1 metre)
(1 joule = 10^7 erg.)

- The British technical unit of work, the foot pound, is the work done by a force of one pound moving its point of application a distance of one foot in the direction that the force is acting.

(1 pound force = 4.448 newton, 1 foot = 0.304 metres)
(1 foot pound = 1.355 joules)

4.4 If a man pulls a roller weighing 1200 pounds a distance of 70 feet along a horizontal surface against a frictional resistance of 100 pounds weight, the work done = force overcome × distance
= 100 × 70
= 7000 foot pounds

Note that the resistance overcome in this case is the frictional force and not the 1200 pounds weight of the roller.

If a man carries a bag of cement weighing 90 pounds up a flight of steps for a vertical height of 10 feet, the work performed against gravity = 10 × 90 = 900 foot pounds. The force overcome in this case is the force of gravity on the cement acting vertically; therefore the distance moved must also be measured vertically. In general, where work is done against gravity, the amount of work done is equal to the weight of the body raised multiplied by the vertical distance through which its centre of gravity is lifted.

4.5 **POWER.** Power is the rate of doing work. For example, a man lifting a 50 pound load 10 feet in 4 seconds is working harder than a man who takes 20 seconds to lift a similar load the same vertical distance. If two engines are lifting equal loads through the same height but one takes only half the time of the other, both engines are doing equal work, but one engine is more powerful than the other as is working at twice the rate.

If work is being performed at a uniform rate, the power $P = \frac{W}{t}$ where w is the work done in time t.

4.6 **UNITS OF POWER.** In any system of units, the unit of power is the rate of working of an agent which is performing unit work in unit time.

- The SI unit of power, the watt (symbol w) is the rate of working of an agent doing one joule of work per second.

  1 watt (W) = 1 joule per second (J/s).

  Common multiples of the watt are the kilowatt and the megawatt.

- The CGS unit of power is the erg per second.

  1 watt = 1 joule/second = 10^7 ergs per second.

- The British technical unit is the foot pound per second.

- Another common unit is the horsepower, which is often used to state the rate of work of an engine.

  1 horsepower (hp) = 550 foot pound per second.
  = 33000 foot pound per minute.
  = 746 watts.

4.7 ENERGY. Energy is the capacity for doing work. To raise a heavy weight, such as a piledriver, some distance vertically above a pile, an amount of work has to be done which is equal to the product of the weight by the vertical distance raised. If the piledriver is allowed to fall on the pile it can do work in driving the pile into the ground; the amount of work done in this operation is equal to the work that was originally done in raising the piledriver. We say that the raised piledriver has energy, or the capacity to do work, and the amount of energy it possesses is equal to the amount of work it can do when its energy is released (Fig. 11).

4.8 UNITS OF ENERGY. The units of energy are those of work detailed in para. 4.2.

One additional unit used in electricity is the kilowatt hour.

energy = rate × time
= kilowatts × hours

The kilowatt hour is the work obtained in one hour from an agent working at a constant rate of 1 kilowatt.

1 kilowatt = 3.6×10^6 joules.

4.9 FORMS OF ENERGY. The law of Conservation of Energy states that energy cannot be created or destroyed. Energy may be changed from one form to another; the total amount of energy remains constant.

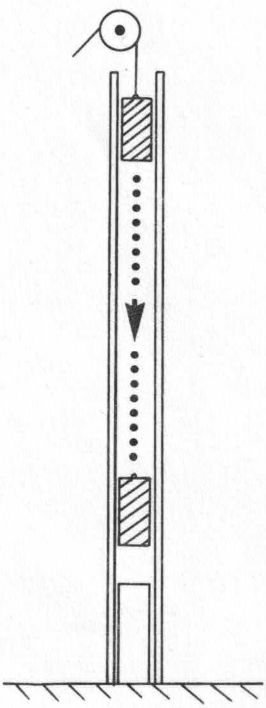


FIG. 11. PILEDRIVER.

Work can be "stored up" in many forms of energy. Food contains chemical energy, which is made available in our bodies as heat and as energy to enable us to move about and do work. Petrol and other fuels also possess chemical energy, which may be converted into mechanical energy to drive a generator. This may be transformed into electrical energy, which in turn may be converted into light energy or heat energy in a lamp, magnetic energy in an electromagnet or sound energy in a telephone bell.

Potential Energy is the energy of position possessed by a body because of its position or state. In the example of the piledriver, the work done in raising it against the force of gravity gives it potential energy or energy of position. When work has been done in stretching, compressing or winding up an elastic body such as a spring, it is also given potential energy, as the spring can do work in returning to its original position or condition. Kinetic Energy is the energy of a body due to its motion. The amount of kinetic energy a body possesses depends on its mass and its velocity W_K = kinetic energy = $\frac{1}{2}m\mu^2$). In the case of our piledriver, the energy it possesses at the top of its scaffolding is all potential energy. As the piledriver falls, its height and therefore its potential energy both decrease, but as it falls its kinetic energy increases because it is moving with ever increasing velocity. As the piledriver falls, its potential energy is converted into an equivalent amount of kinetic energy which is dissipated as heat when the pile is driven into the ground.

The energy of a pendulum at the top of its swing is all potential. At the instant it passes through its lowest point the energy has all been converted to kinetic, and it is changed again to potential as it rises again on the other side. The pendulum eventually comes to rest as some energy is being continually converted into heat in overcoming frictional resistance of the air and the pendulum support.

NOTES

NOTES

5. TEST QUESTIONS.

1. *Give one example of a misleading assumption that might be made when based on sensory responses.*

2. *State the six quantities which form the basis of the S.I. system of units. Give the unit for each of the basic quantities.*

3. *Explain the difference between basic units and derived units. Give an example of each.*

4. *What is meant by a coherent system of units?*

5. *State the factor by which the basic unit should be multiplied when prefixed by each of the following:-*

   (i) giga (ii) milli (iii) pica (iv) mega (v) micro.

6. *If there are 1760 yards in a mile, and 1 metre is approximately equal to 39.37 inches, calculate the number of yards in one kilometre.*

7. *What is the miles per hour equivalent of a speed of 60 kilometres per hour?*

8. *When using a rule to take measurements, why is it advisable to commence measurements from one of the major divisions rather than the end of the rule?*

9. *When measuring the width of a board, the rule should be at right angles to the edge of the board. What is the effect on the measurement if the rule is not held at right angles to the edge?*

10. *Explain what is meant by the term "parallax error".*

11. *Use a simple sketch to explain how an auxiliary or vernier scale is able to assist in estimating fractions of a main scale division.*

12. *List several measuring instruments which use a vernier to obtain greater accuracy in measurements.*

13. *List four methods of measuring diameters of objects having a circular cross-sectional area.*

14. *What is meant by the term "meniscus" as applied to liquid in a container?*

15. *If 1 litre = 1.76 pints, and 1 litre = 1000 cubic centimetres, calculate the number of cubic centimetres in one gallon.*

16. *Calculate the volume in cubic centimetres of a sphere having a diameter of 6 inches. (1 inch = 2.54cm).*

17. *Explain one method of measuring the volume of an irregular solid such as an iron bolt.*

18. *Calculate the relationship between joules and ergs if 1 newton = 10^5 dyne and 10^2cm. = 1 metre.*

19. *If 1 foot pound = 1.355 joules, calculate the work performed if a man carried a 100lb. bag of sugar up a flight of stairs to a landing which is 10 feet from the ground.*

TEST QUESTIONS (CONT'D)

20. *In physics, what is meant by the term "power"?*

21. *Calculate in watts the rate of working of a man who lifts 100 lb. a distance of 200 ft. in 10 seconds.*

22. *Explain the relationship between work and energy.*

23. *Give four examples of transformation of energy.*

24. *What is the SI force unit?*

25. *Explain the difference between force and work.*

END OF PAPER.